

# TA/TALE Results and Prospects

## TAUP-2013

### Asilomar, CA

Pierre Sokolsky  
University of Utah

# Outline

- Status of TA
- Spectrum
- Composition
- Anisotropy
- TALE- TA low energy extension
- TARA – Bistatic radar detection of Cosmic Rays
- ELS –Calibration and JEM-EUSO studies
- TALMA- Lightning studies
- NICHE – Cherenkov array for low energy studies



# Telescope Array Collaboration

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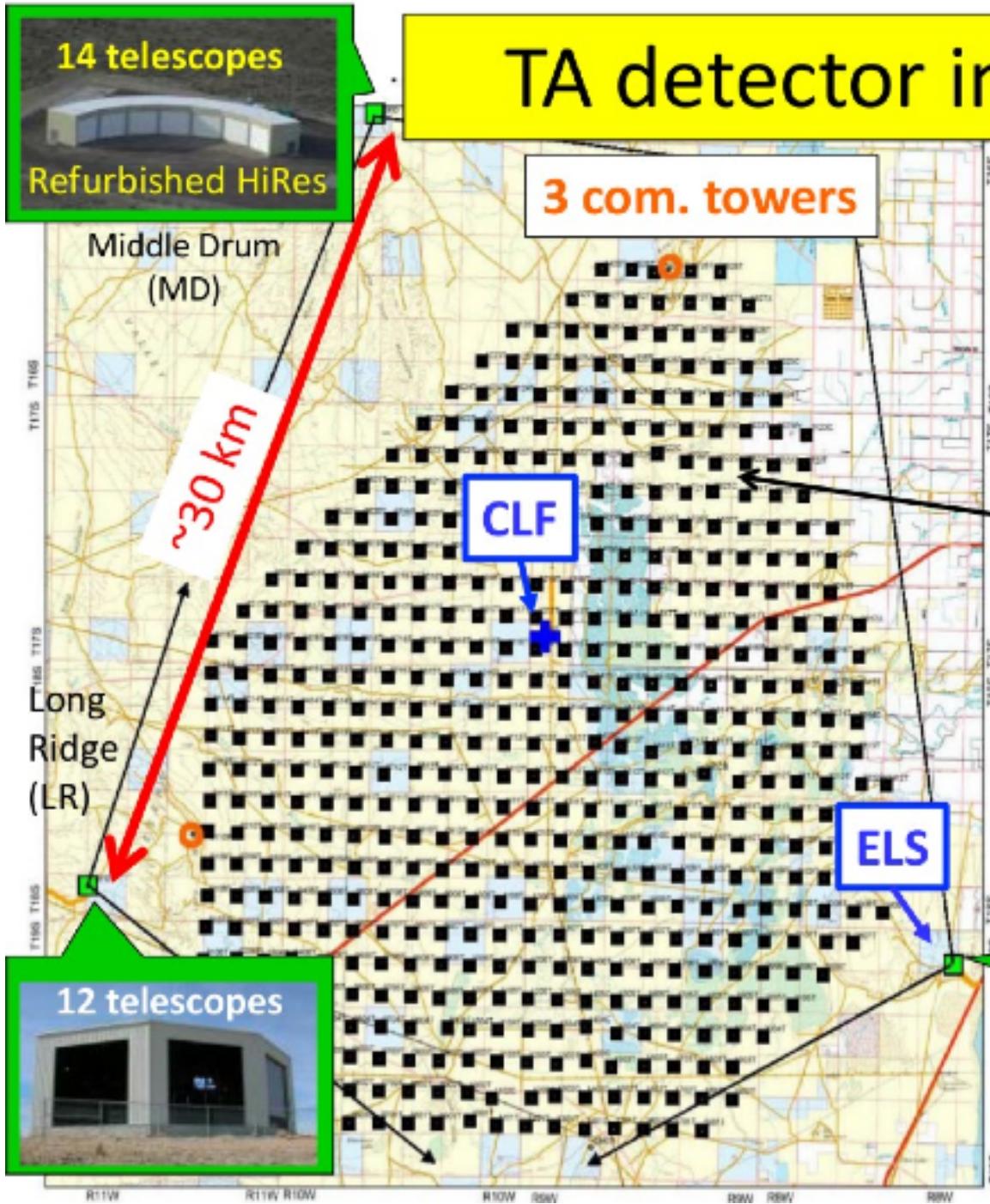
<sup>p</sup>Rutgers University, <sup>q</sup>Tokyo City University, <sup>r</sup>Institute for Nuclear Research of the Russian Academy of Sciences, <sup>t</sup>Waseda University,

<sup>s</sup>Chiba University, <sup>ac</sup>Institute of Particle and Nuclear Studies, KEK, <sup>ad</sup>Kochi University, <sup>b</sup>Ritsumeikan University, <sup>y</sup>Sungkyunkwan University,

<sup>x</sup>Universite Libre de Bruxelles, <sup>y</sup>Chungnam National University, <sup>z</sup>Earthquake Research Institute, University of Tokyo,

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# TA detector in Utah



## Surface Detector (SD)

507 plastic scintillator SDs  
1.2 km spacing  
700 km<sup>2</sup>



## Fluorescence Detector(FD)

3 stations  
38 telescopes



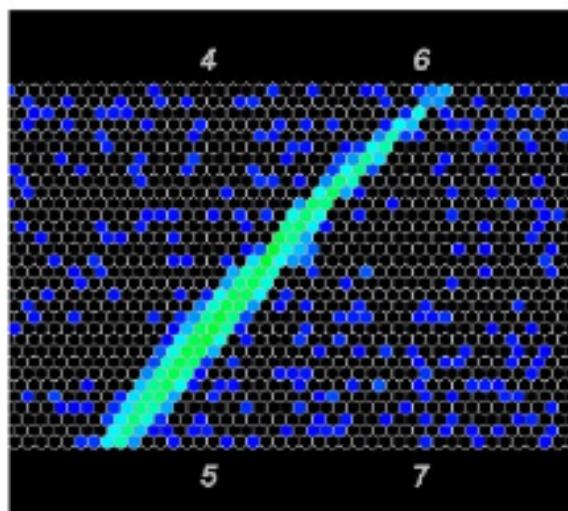
12 telescopes

Black Rock Mesa (BR)

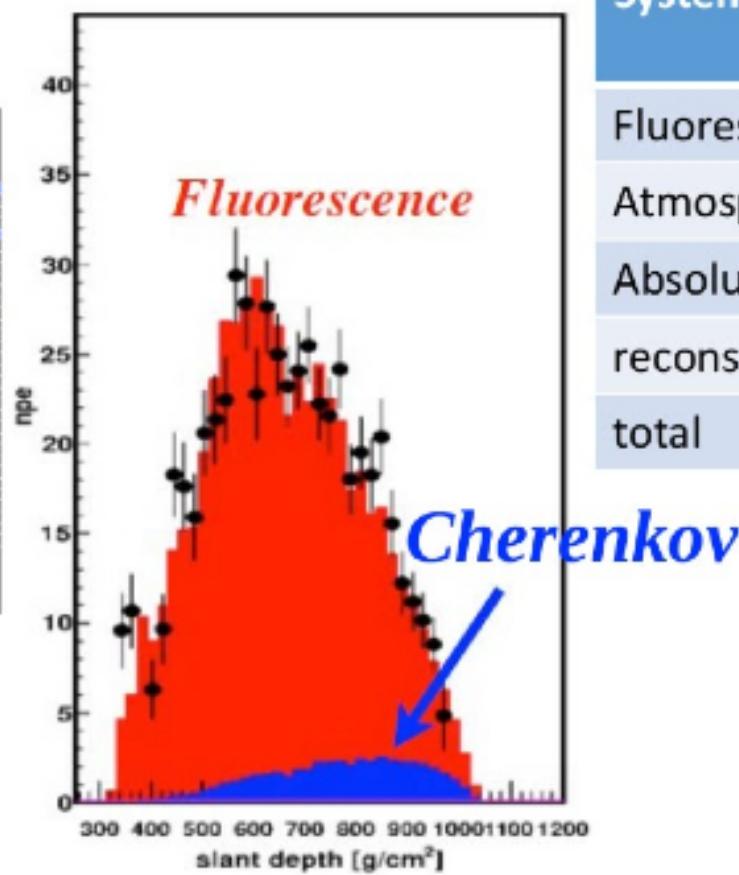
5

# TA shower analysis with FD

An example of an air shower  
the camera view

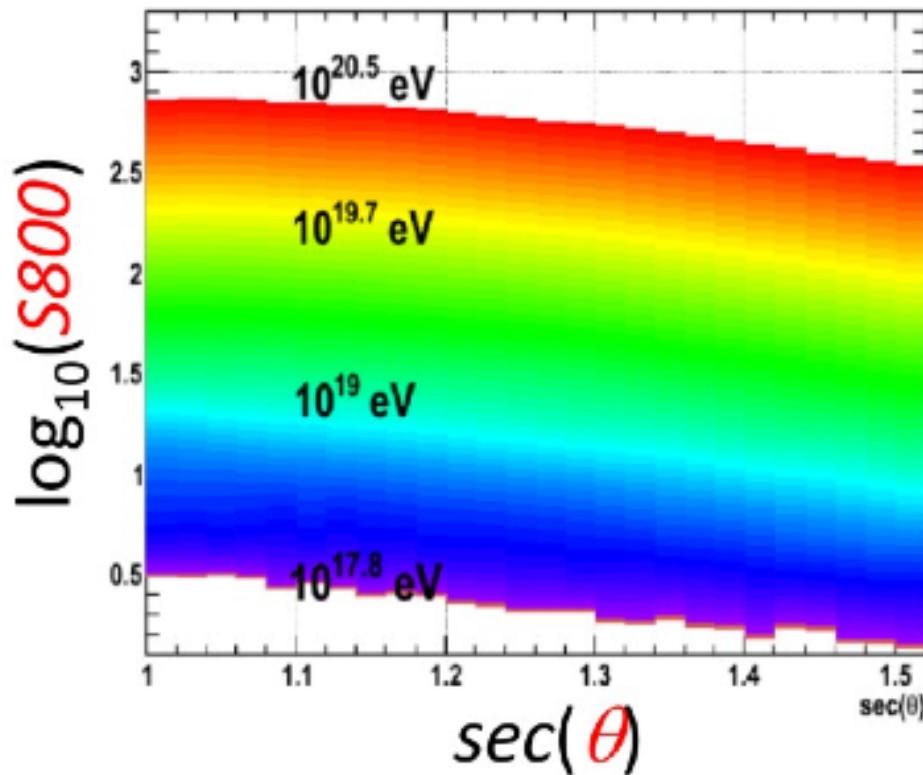


Longitudinal shower profile

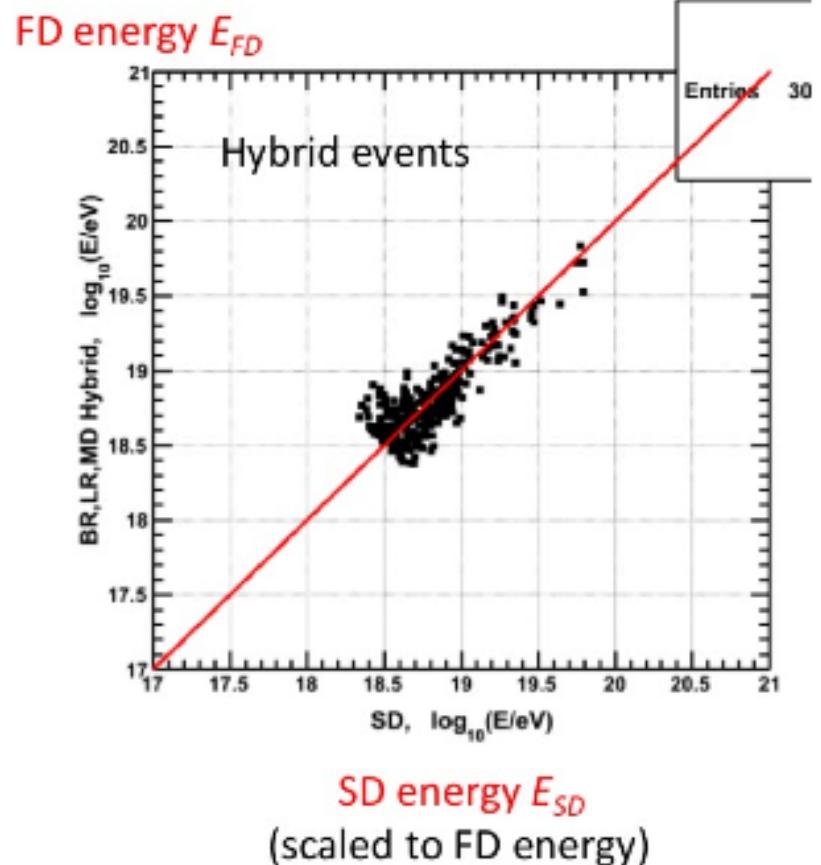


Systematic uncertainty in energy determination	
Fluorescence yield	11%
Atmospheric attenuation	11%
Absolute detector calib.	10%
reconstruction	10%
total	21%

# SD/FD Energy Scale



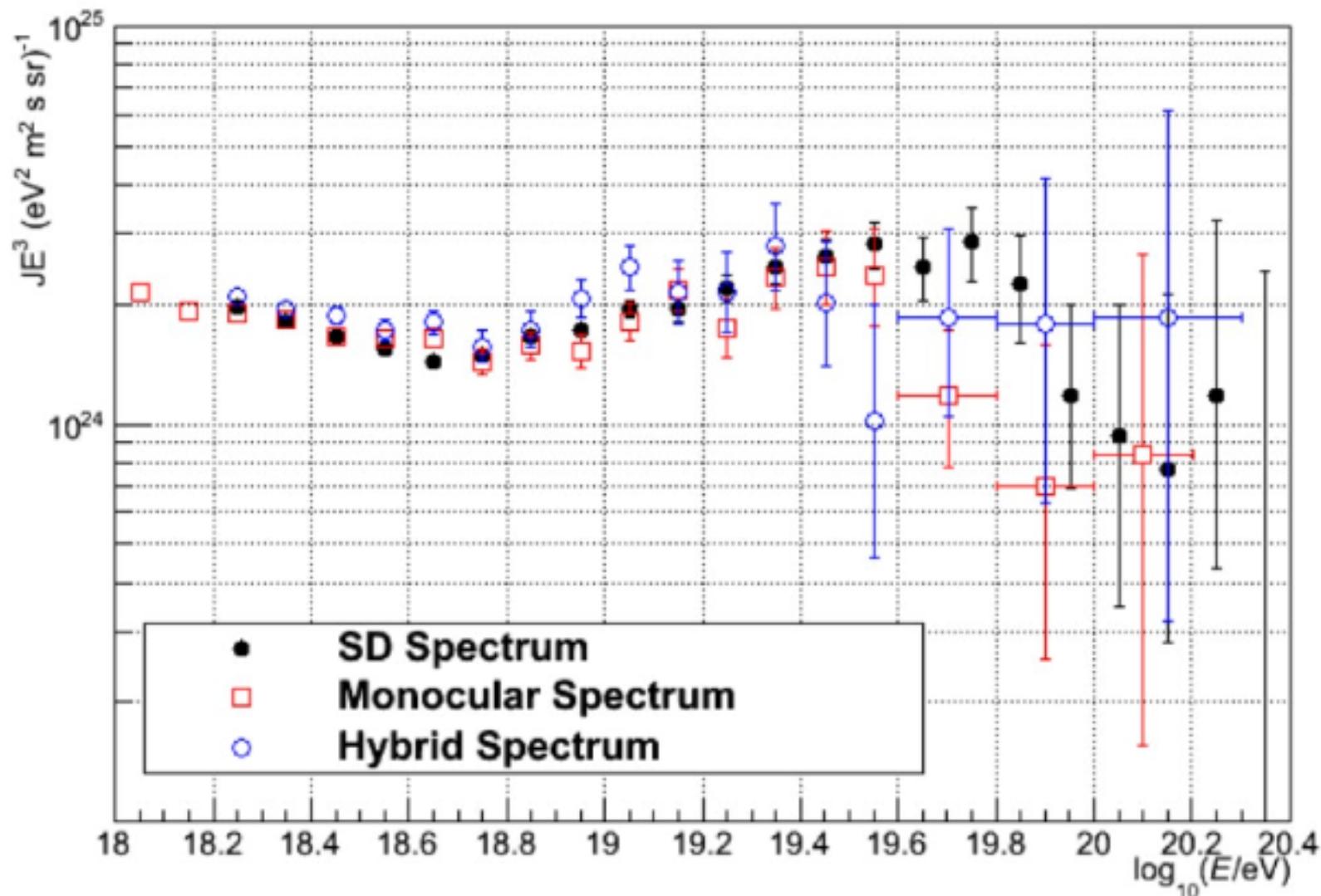
First estimate of SD Energy: MC lookup table



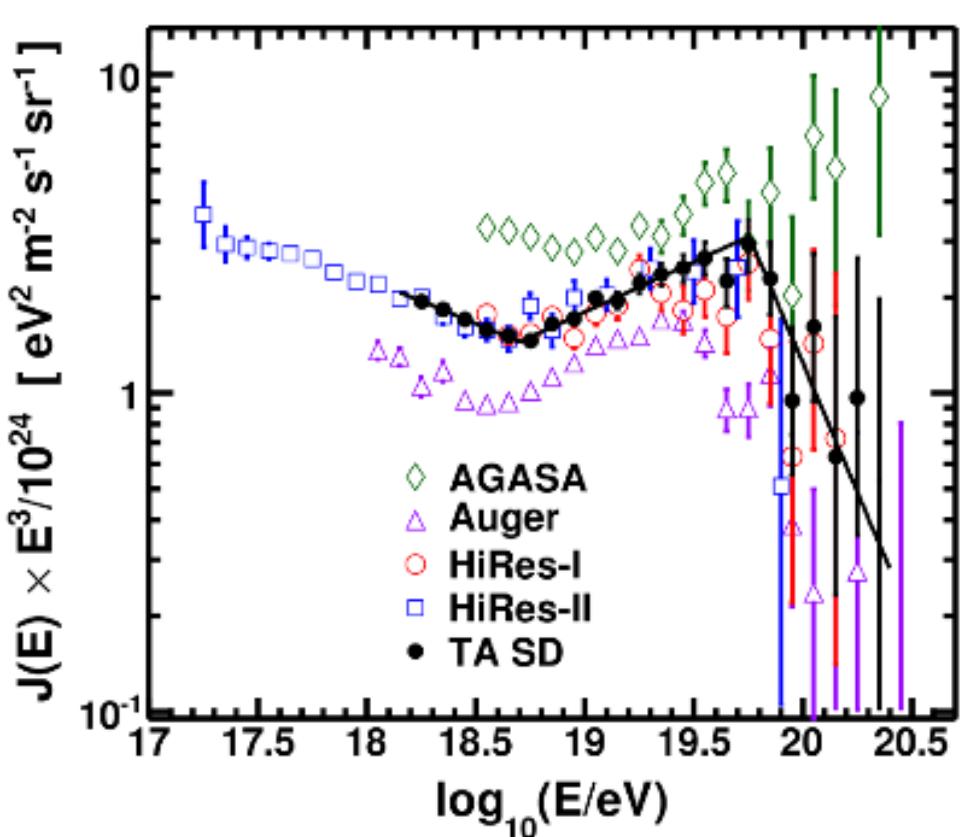
$$E_{SD} = E'_{SD} / 1.27$$

# Spectrum overview

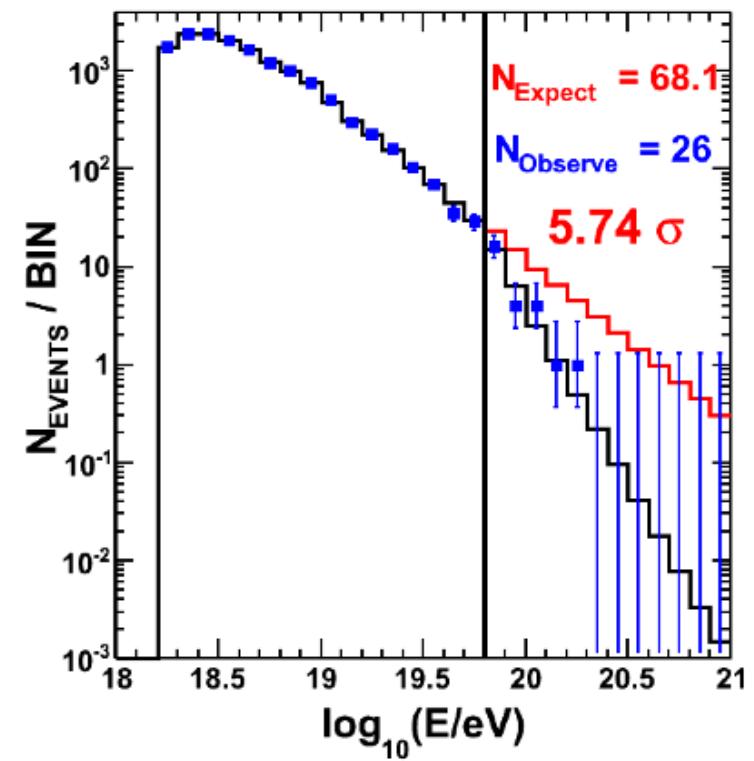
## SD, Monocular and Hybrid Spectra



# Comparison with other experiments and significance



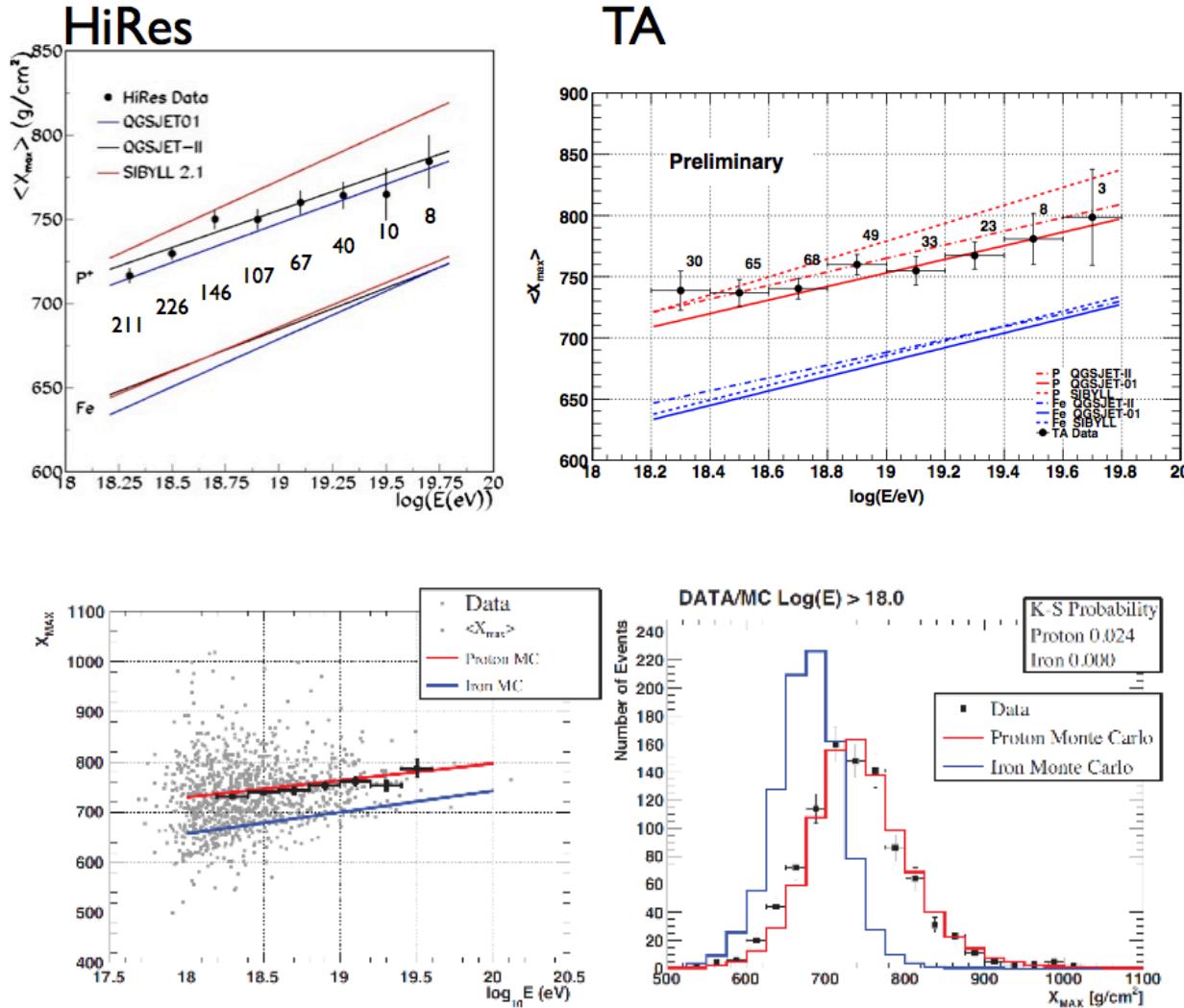
Significance of suppression



# Status of GZK Cutoff

- Now observed with multiple methods
- HiRes – Fluorescence – 5 sigma
- PAO – Cherenkov water + Fluorescence > 20sig
- TA – Plastic scintillator + Fluorescence > 5 sig
- Energy within 20% of each other – within systematics
- TA SD is 1.27 x higher energy than FD. Explains AGASA normalization.
- Are these particles protons?

# Composition – Elongation Rate



Hybrid (MD) TA

# Composition –North/South Difference?

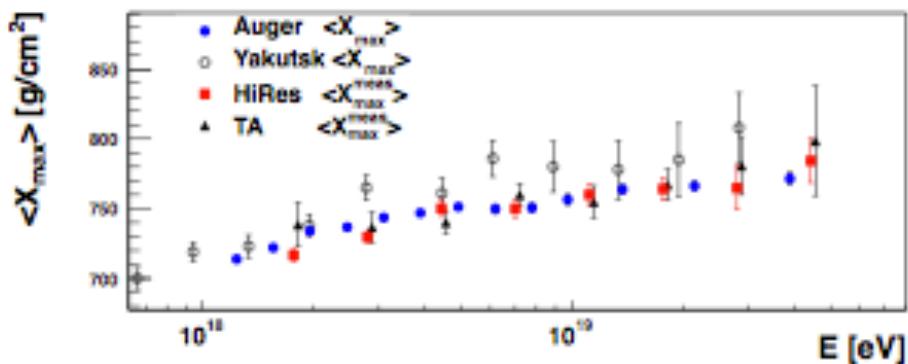
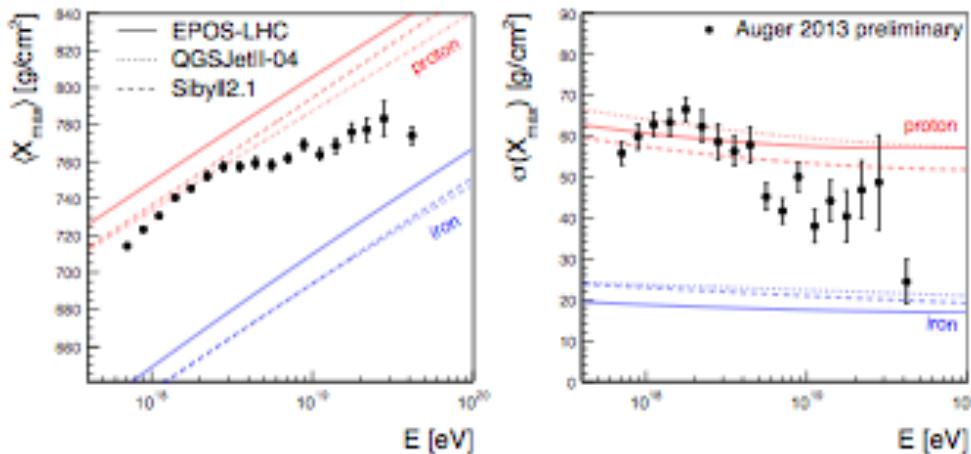


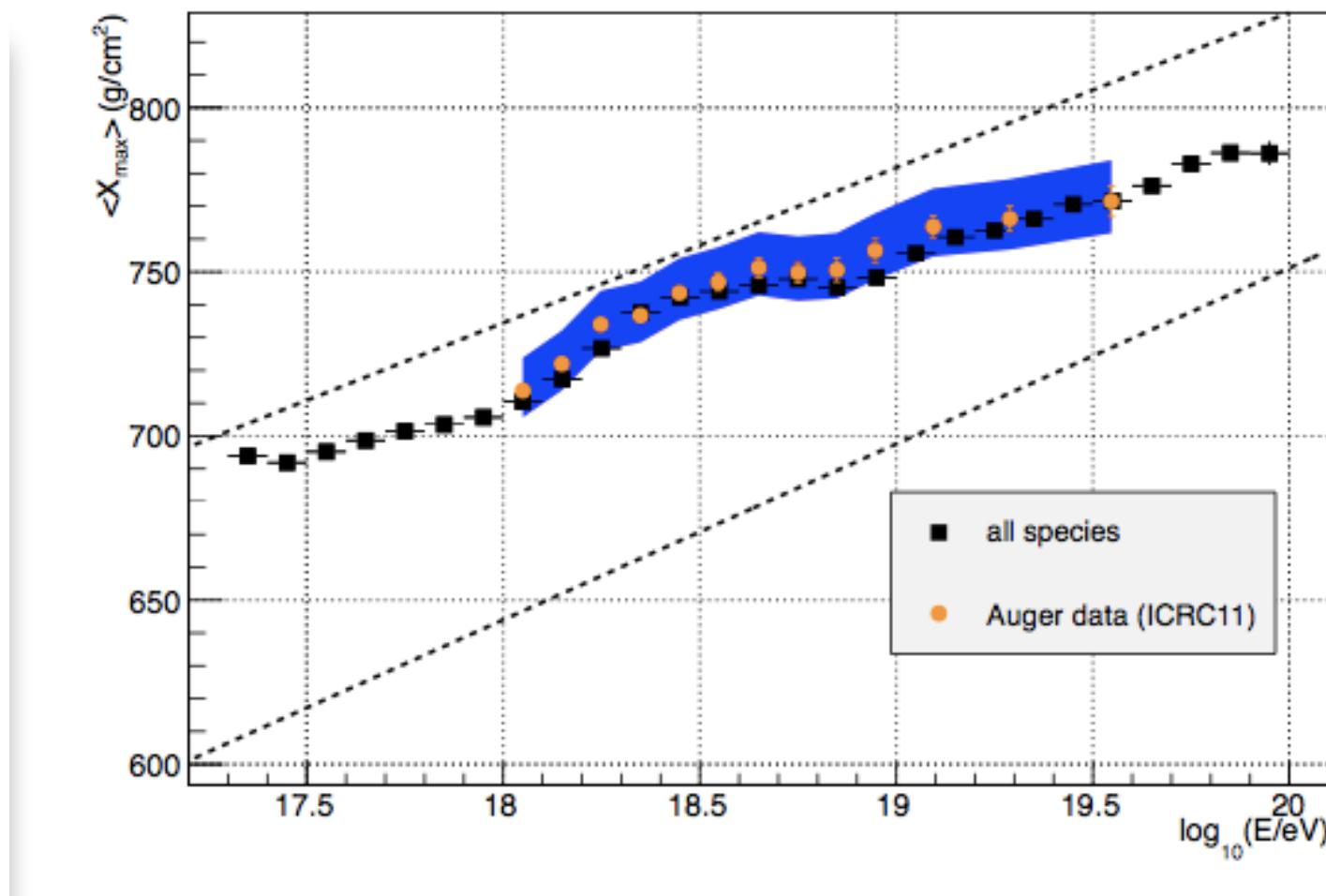
Fig. 2.  $\langle X_{\max} \rangle$  measured by Auger and Yakutsk, together with the  $\langle X_{\max}^{\text{meas}} \rangle$  as measured by HiRes and TA. Data points are shifted to a common energy scale (text for details).

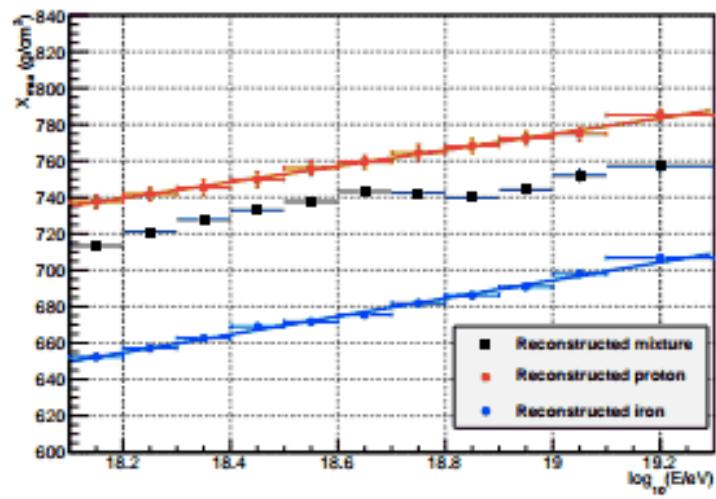


Most recent  
PAO result

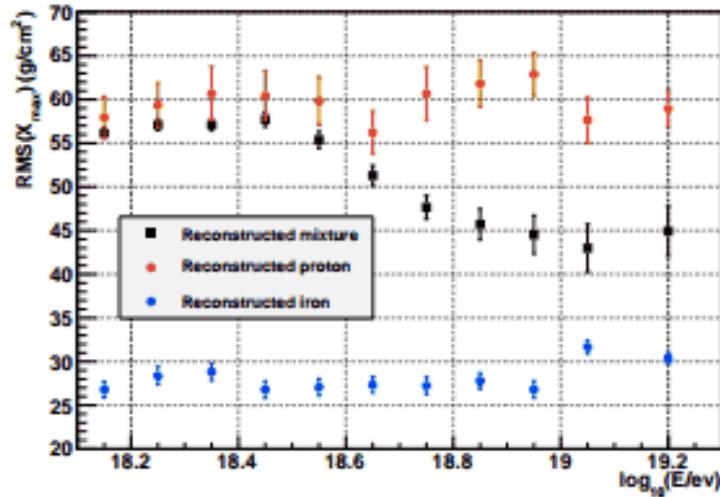
# Auger-TA Composition Working Group

## Development of TA-hybrid prediction model





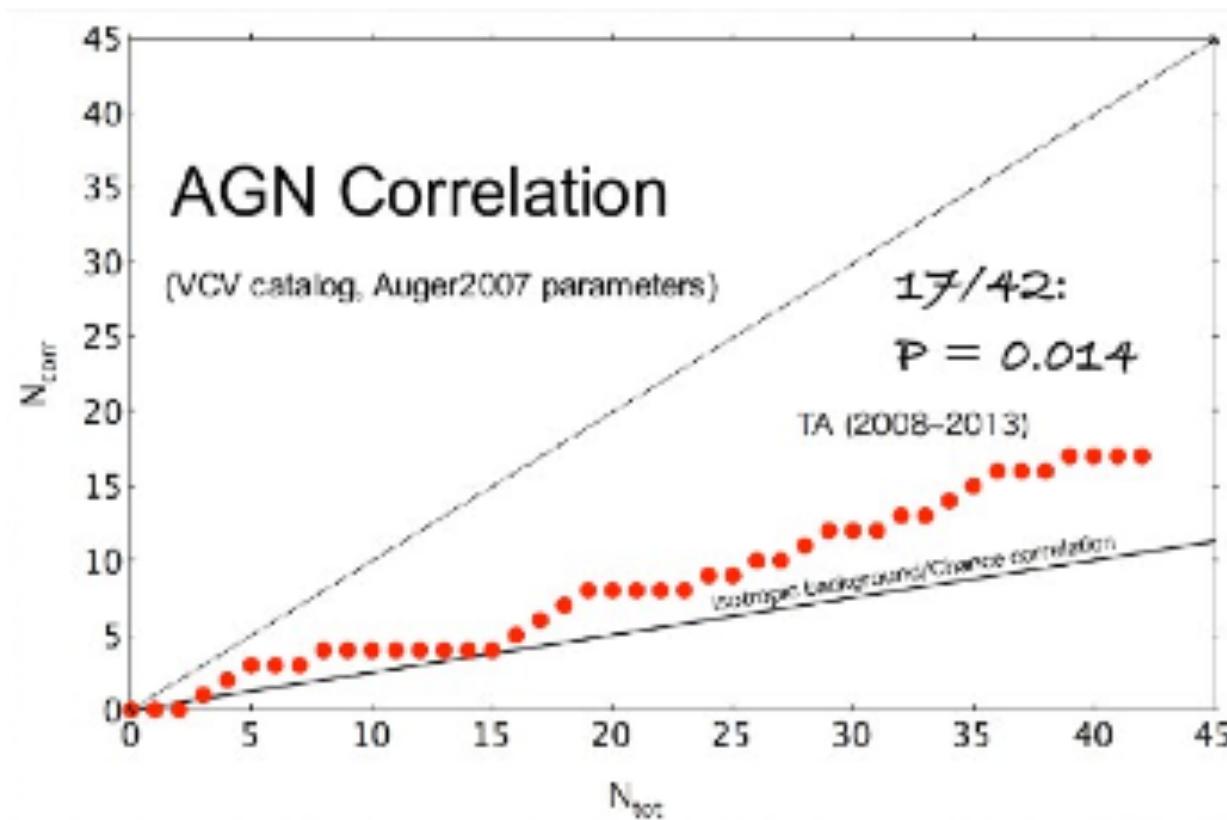
Reconstructed hybrid TA simulated Data for pure protons, PAO mix and Pure Iron, for both mean  $X_{\text{max}}$  And RMS of  $X_{\text{max}}$  distribution – including All acceptance and resolution effects.



TA hybrid will be able to cleanly Distinguish between these three hypotheses

TA hybrid comparison is expected In near future

# Anisotropy – Correlations with AGN catalog



# Local LSS as source of UHECR

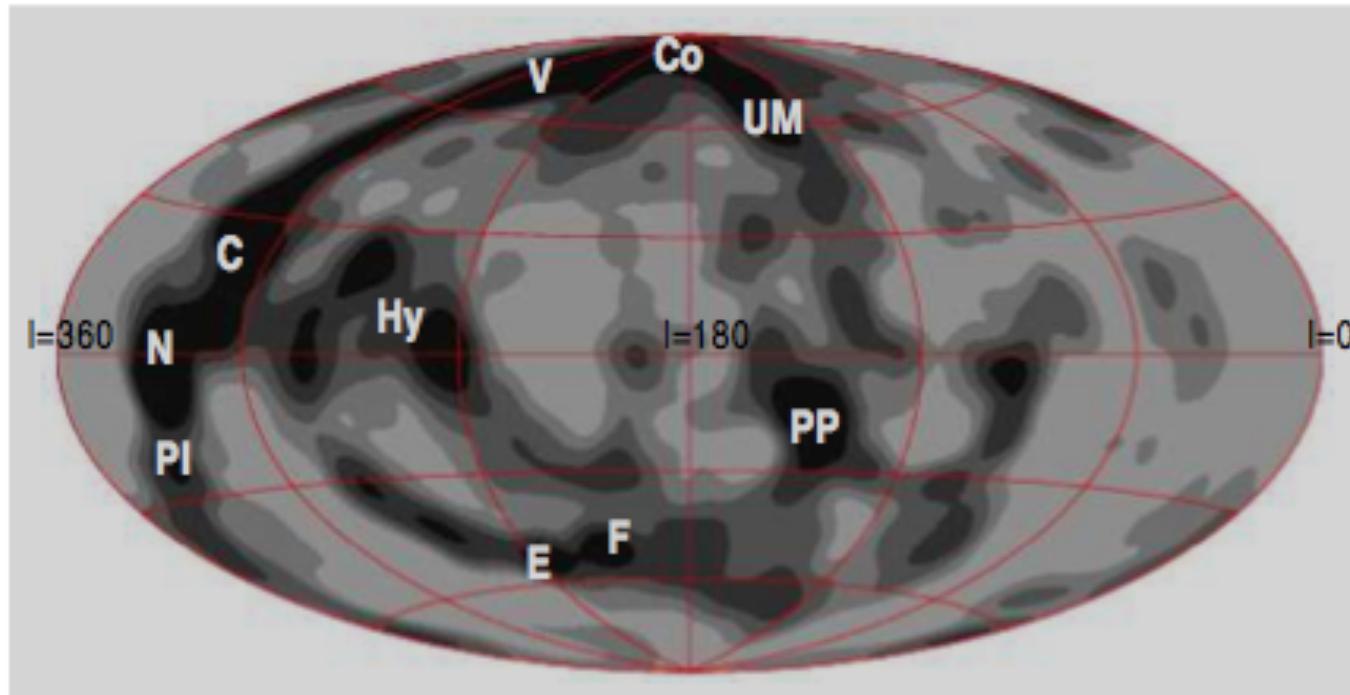
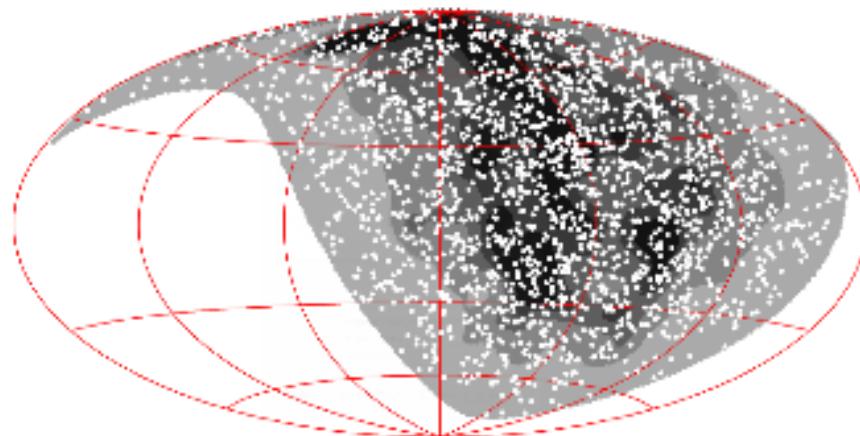


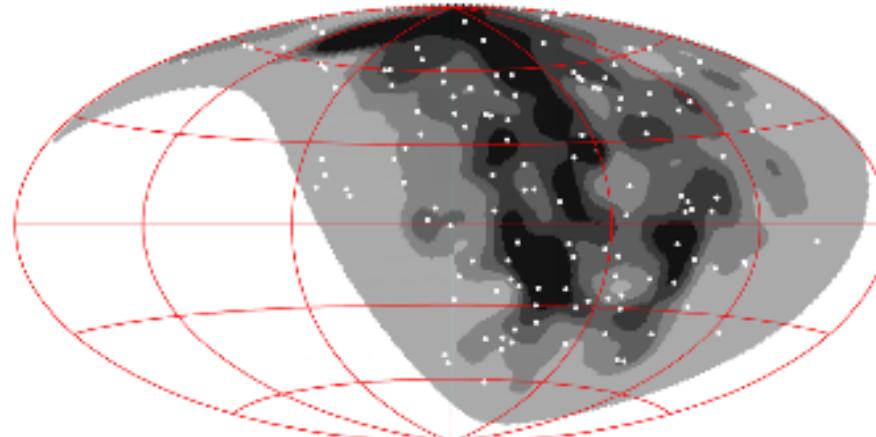
FIG. 5.— Sky map of expected flux at  $E > 57$  EeV (Galactic coordinates). The smearing angle is  $6^\circ$ . Letters indicate the nearby structures as follows: **C**: Centaurus supercluster (60 Mpc); **Co**: Coma cluster (90 Mpc); **E**: Eridanus cluster (30 Mpc); **F**: Fornax cluster (20 Mpc); **Hy**: Hydra supercluster (50 Mpc); **N**: Norma supercluster (65 Mpc); **PI**: Pavo-Indus supercluster (70 Mpc); **PP**: Perseus-Pisces supercluster (70 Mpc); **UM**: Ursa Major (20 Mpc); **V**: Virgo cluster (20 Mpc).

# Correlations with LSS

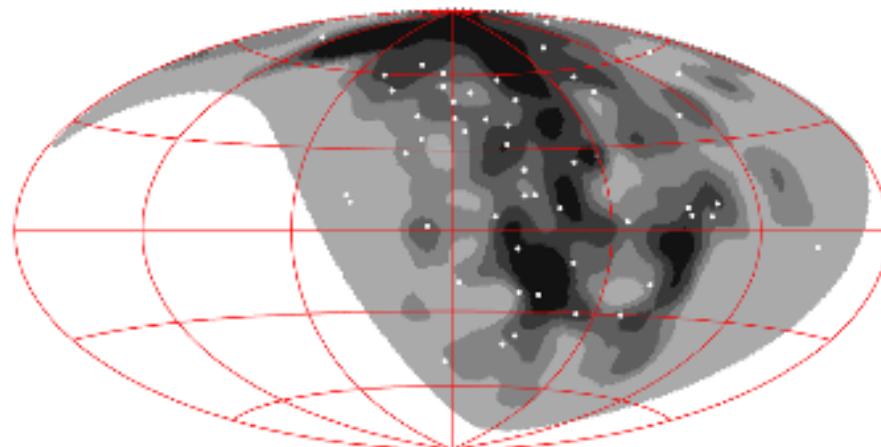
$E > 10 \text{ EeV}$ : 2130 ev.



$E > 40 \text{ EeV}$ : 132 ev.



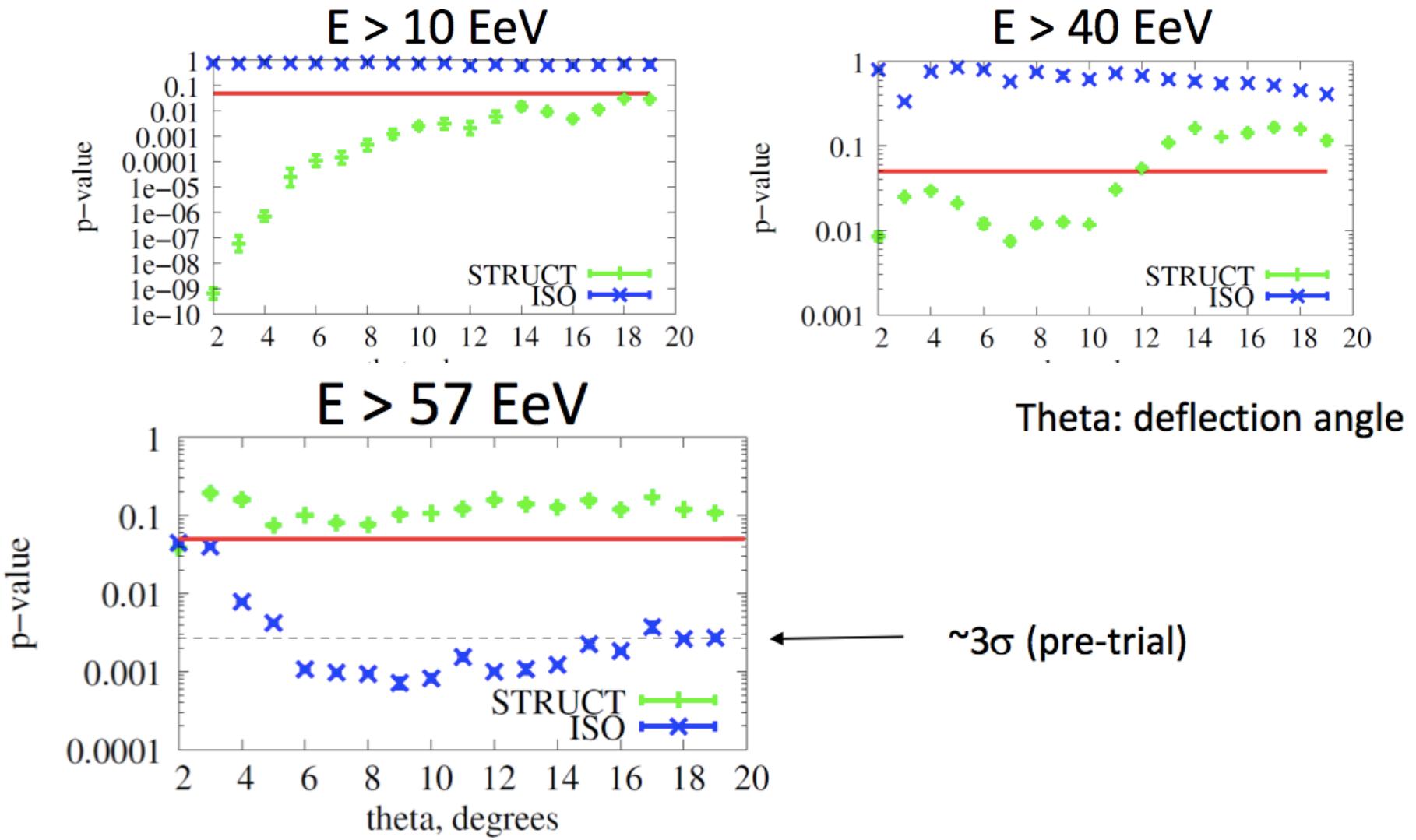
$E > 57 \text{ EeV}$ : 52 ev.



White dots: TA data with zenith angle  $< 55^\circ$

Gray patterns:

expected flux density from proton LSS  
2MASS Galaxy Redshift catalog (XSCz)



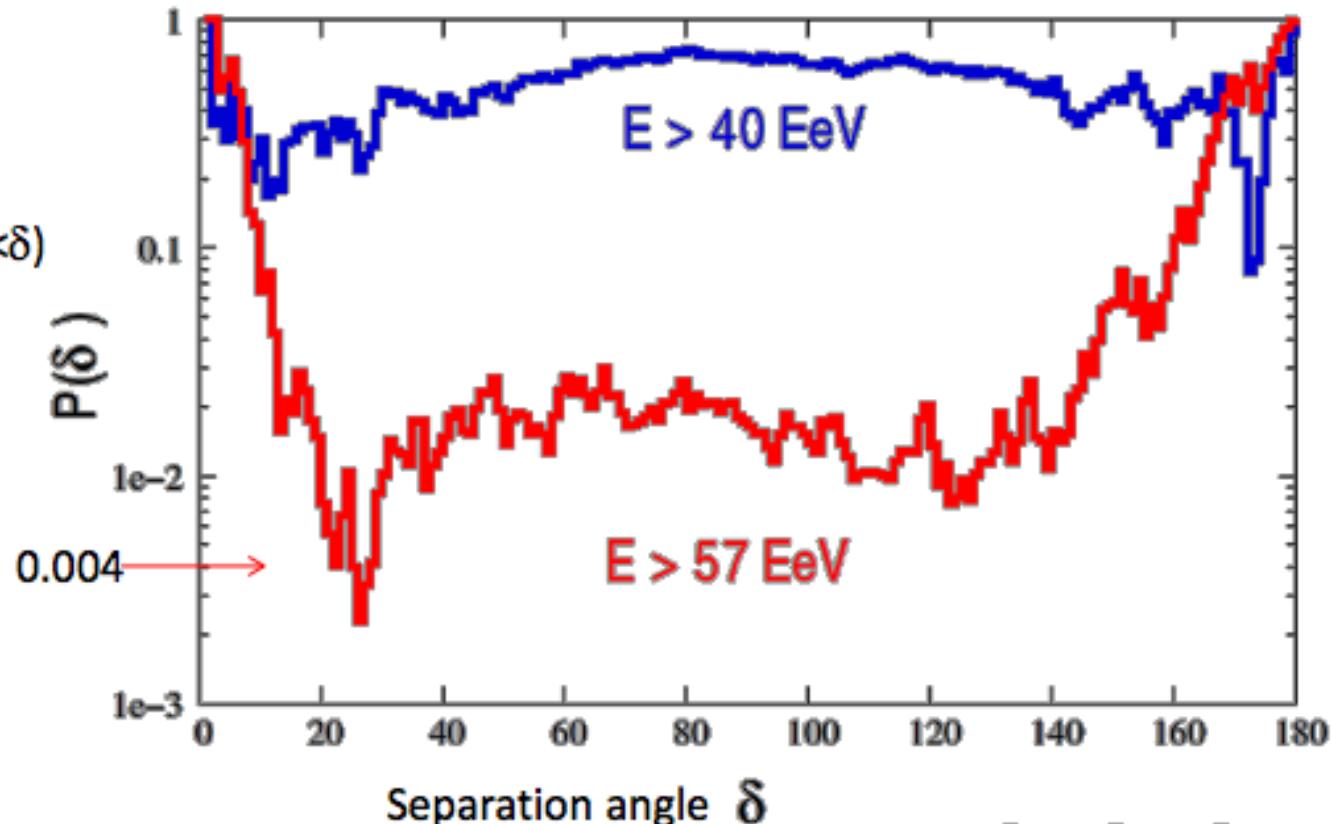
# Autocorrelations

$P(\delta)$ :

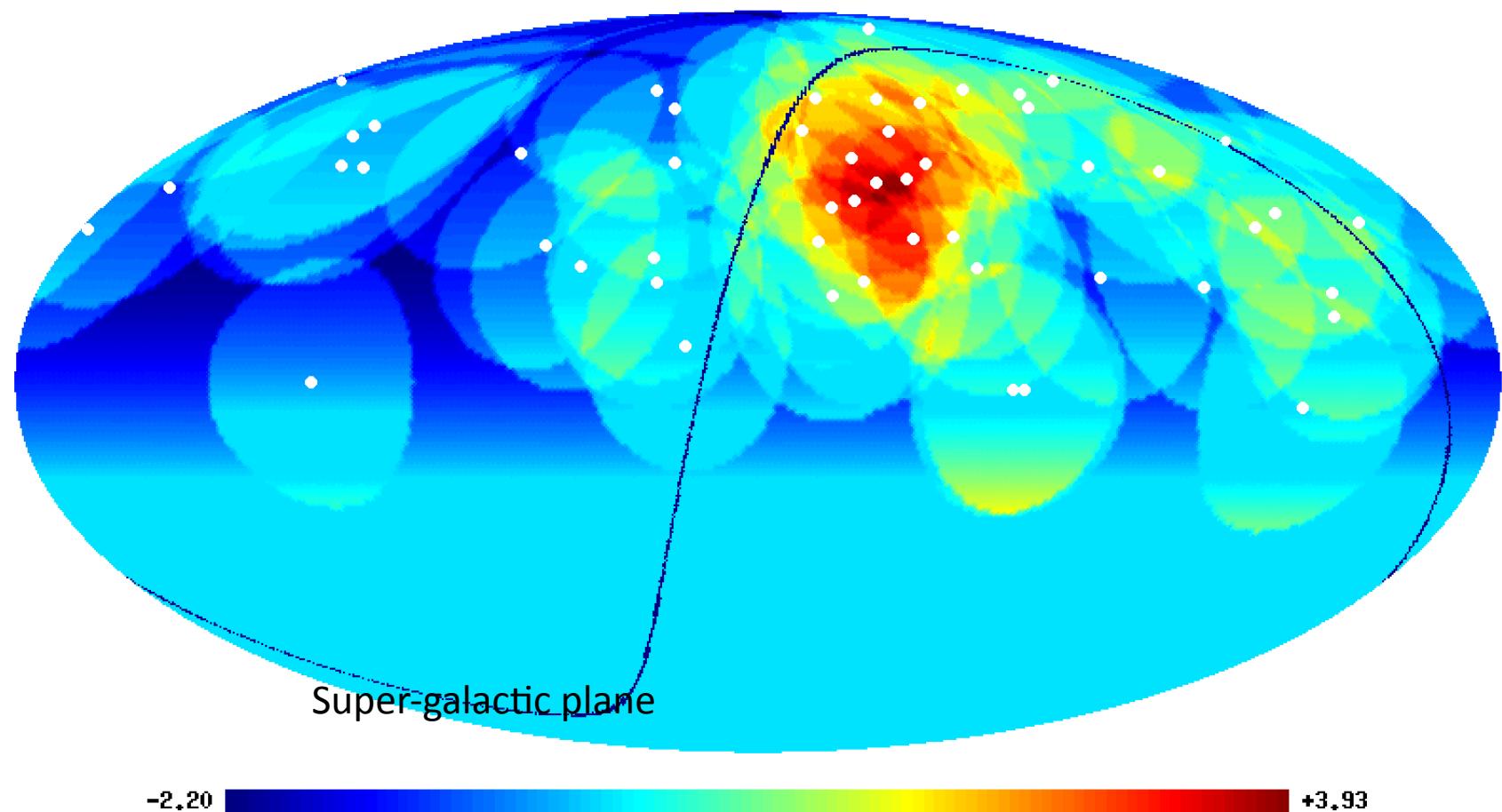
The probability that  
the excess of pairs ( $<\delta$ )  
occurs in a uniform  
distribution

Small  $P(\delta)$ :

departure from  
isotropy

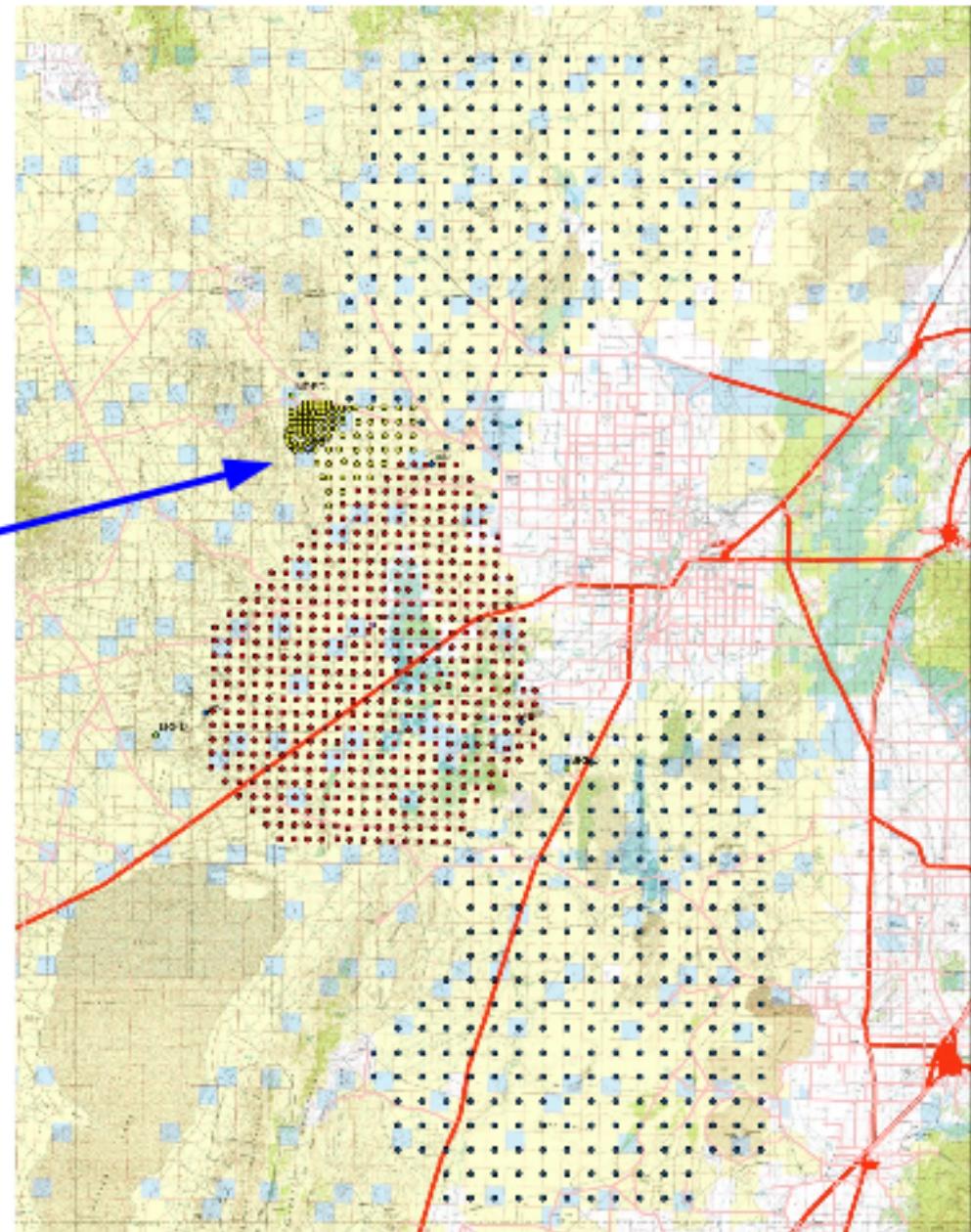


# Relative correlation significance averaged over 25 deg.circles



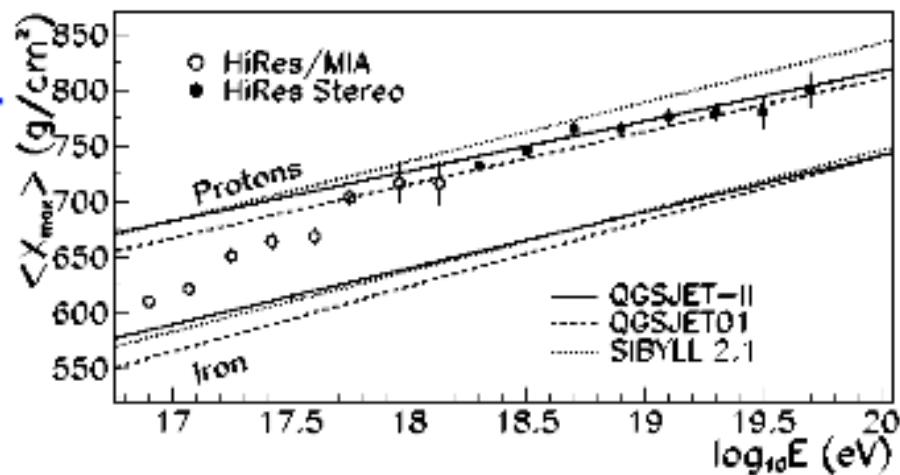
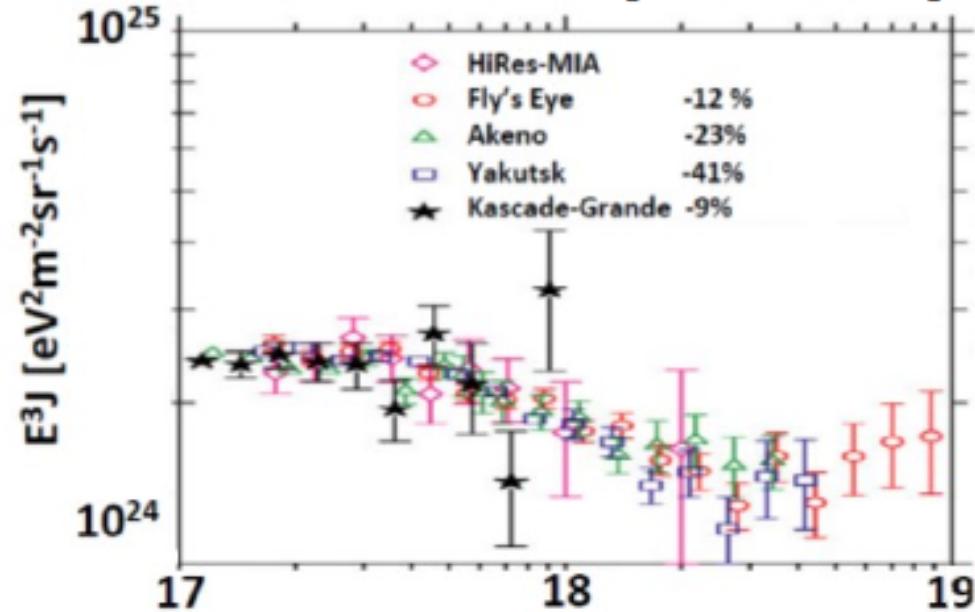
# TA Upgrades

- Low-energy extension; TALE

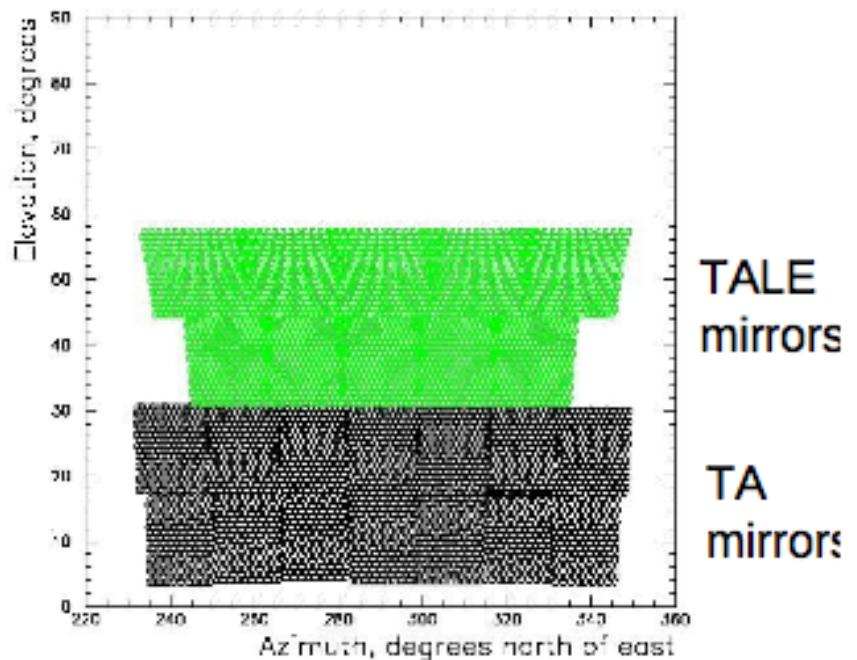
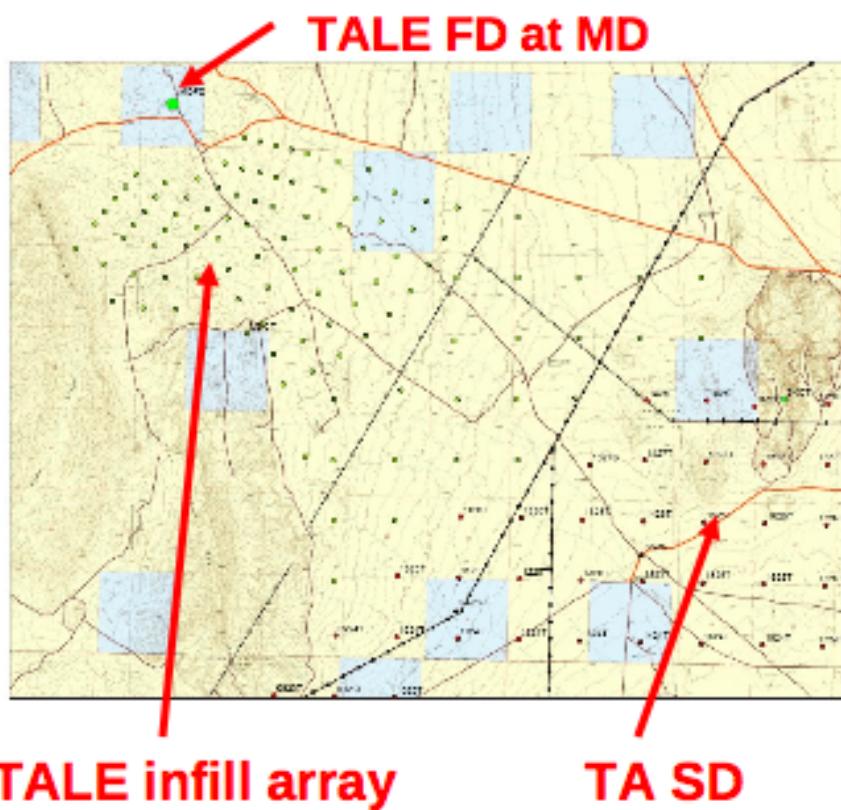


# TA Low Energy Extension (TALE)

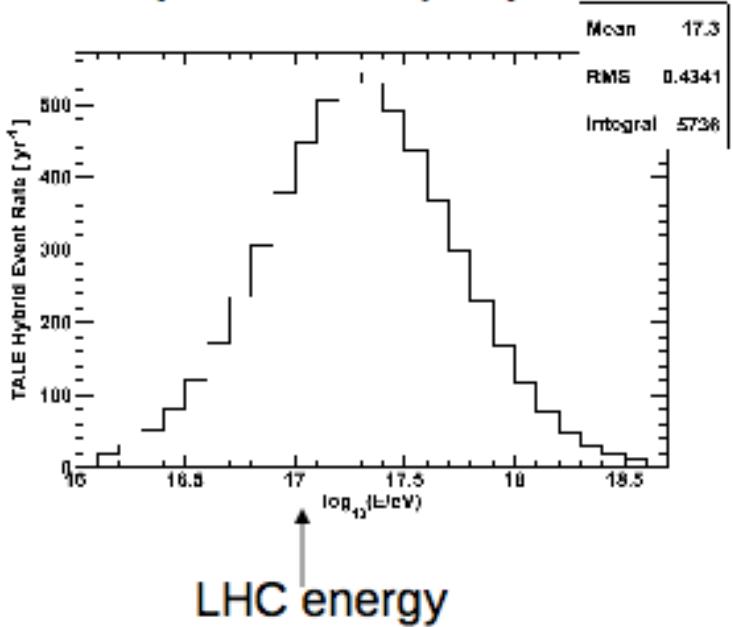
- Study  $10^{16}$  and  $10^{17}$  eV decades in hybrid
- Astrophysics
  - End of “knee”
  - Second knee
  - Galactic-Extragalactic Transition
- High-energy physics: Cross-section measurements overlapping LHC



# TALE Detectors are being deployed.



TALE hybrid events per year



# TALE is now taking data

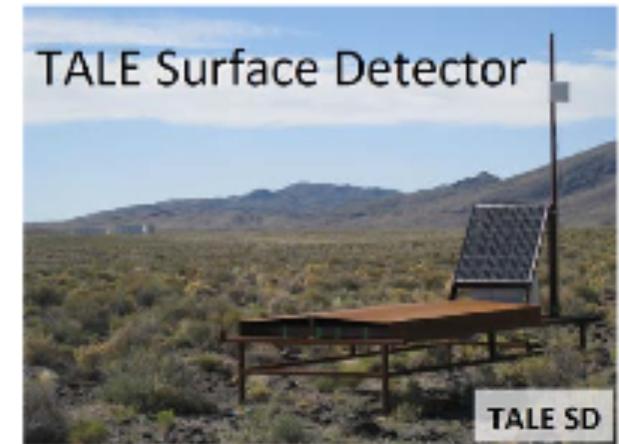
- 10 TALE FDs:

- refurbished HiRes-II telescopes
- installed and running.



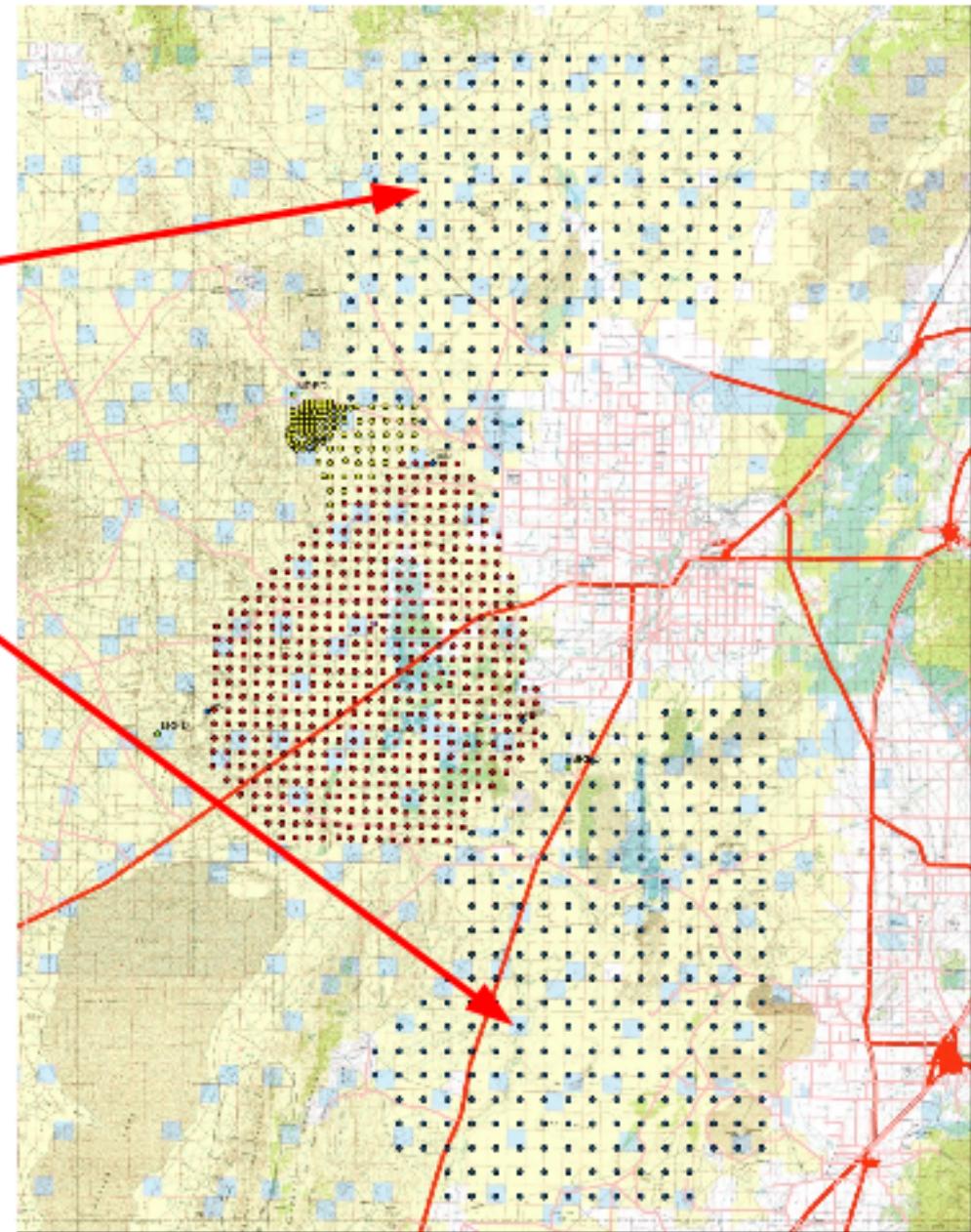
- TALE SDs

- 35 TALE SDs were deployed among 101 SDs.
- 16 in operation



# TA Upgrades

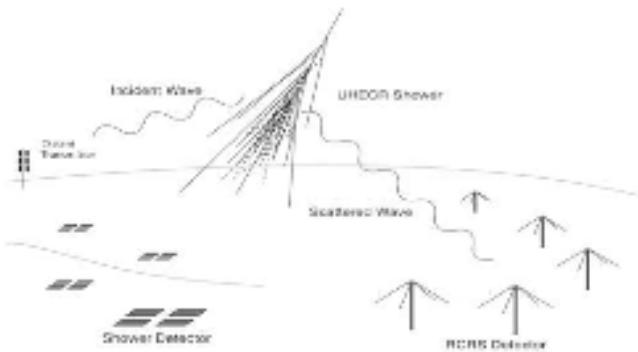
- TA x 4
- 3,000 km<sup>2</sup>
  - 500 SD's, 2 km spacing
  - 1 new FD (HiRes refurbished)
- Proposals fall 2013
- Anisotropy: 20 TA-SD years by 2019



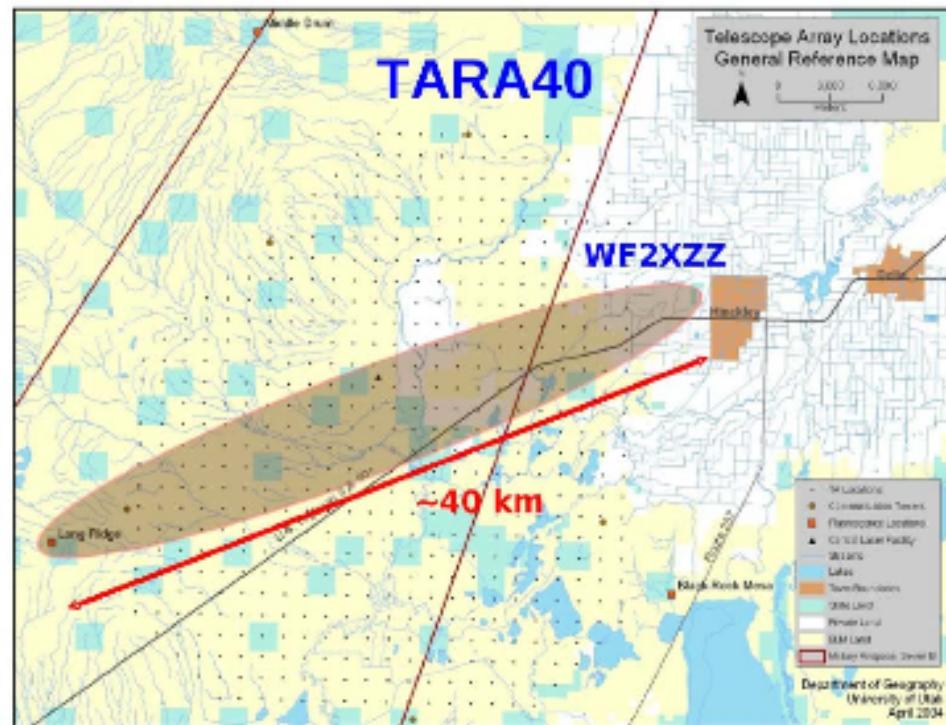
# TARA (TA Radar)

J. Belz et al., oral 1192  
I. Meyer et al., poster

- An R&D project to observe radar reflections from cosmic ray air showers

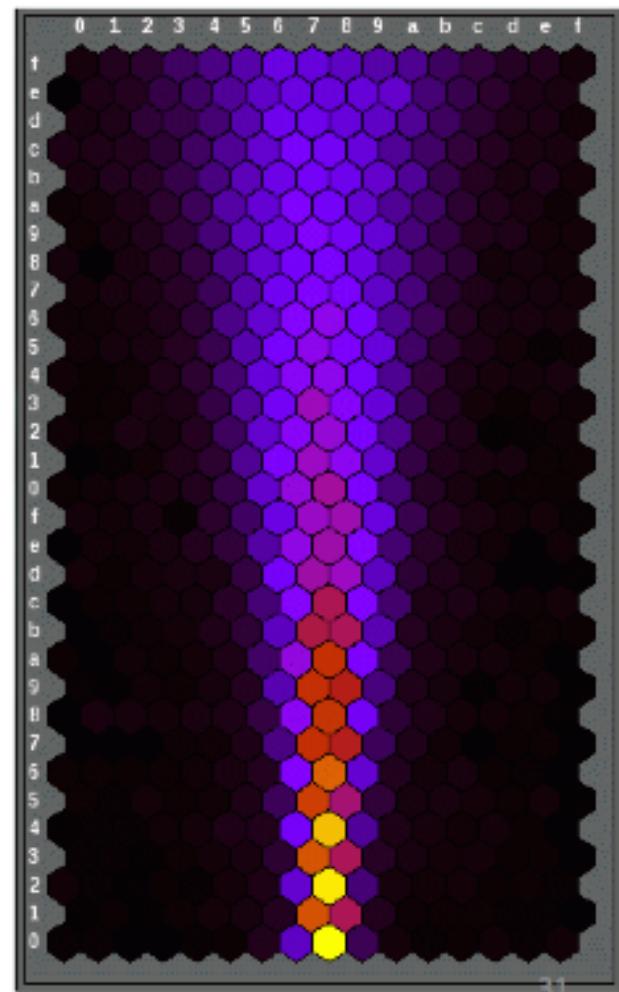
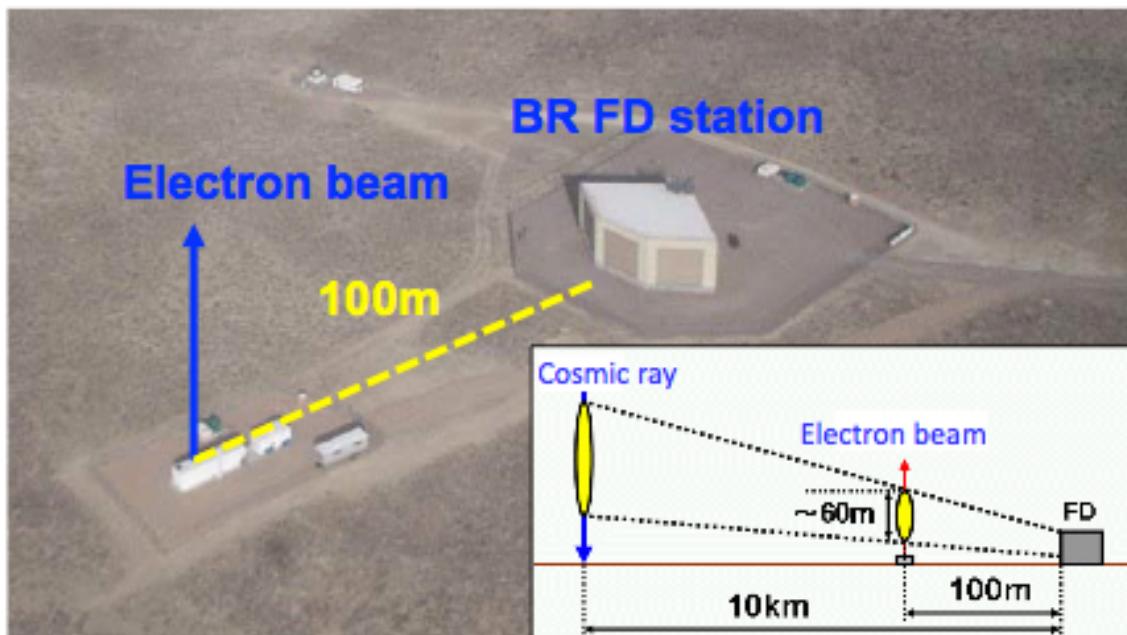


- **TARA1.5**
  - April 2011 to July 2012
  - 54.1 MHz @ 1.5 kW
- **TARA40**
  - Summer 2013~
  - 54.1 MHz @ 40 kW



# Electron Light Source (ELS)

An image of data  
Measured with FD

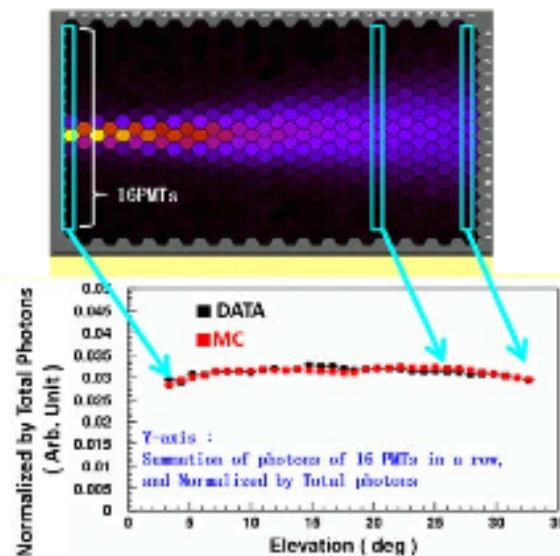


- 40-MeV,  $10^9$  electrons (typical)
- End-to-end FD energy calibration

# ELS analysis

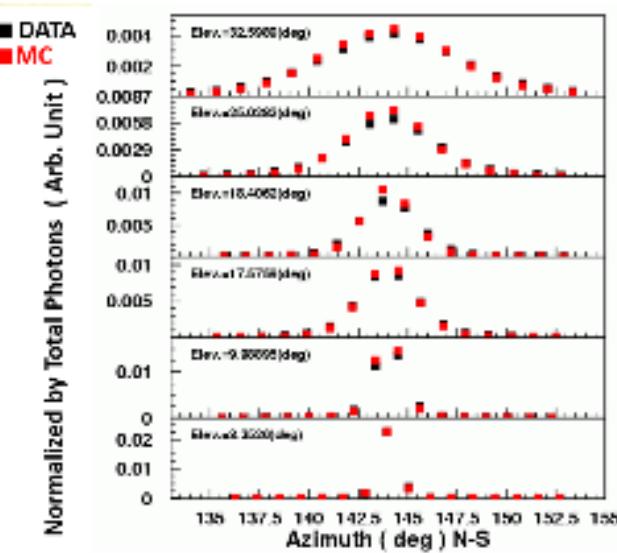
- Real data
  - ELS
    - Energy/beam current from monitor
    - FADC counts from FD
- MC data
  - Shower generation
    - Geant4.9.5 or 4.9.6
  - FD simulation
    - TA official software

Longitudinal distribution



Data/MC agreement: within 5%

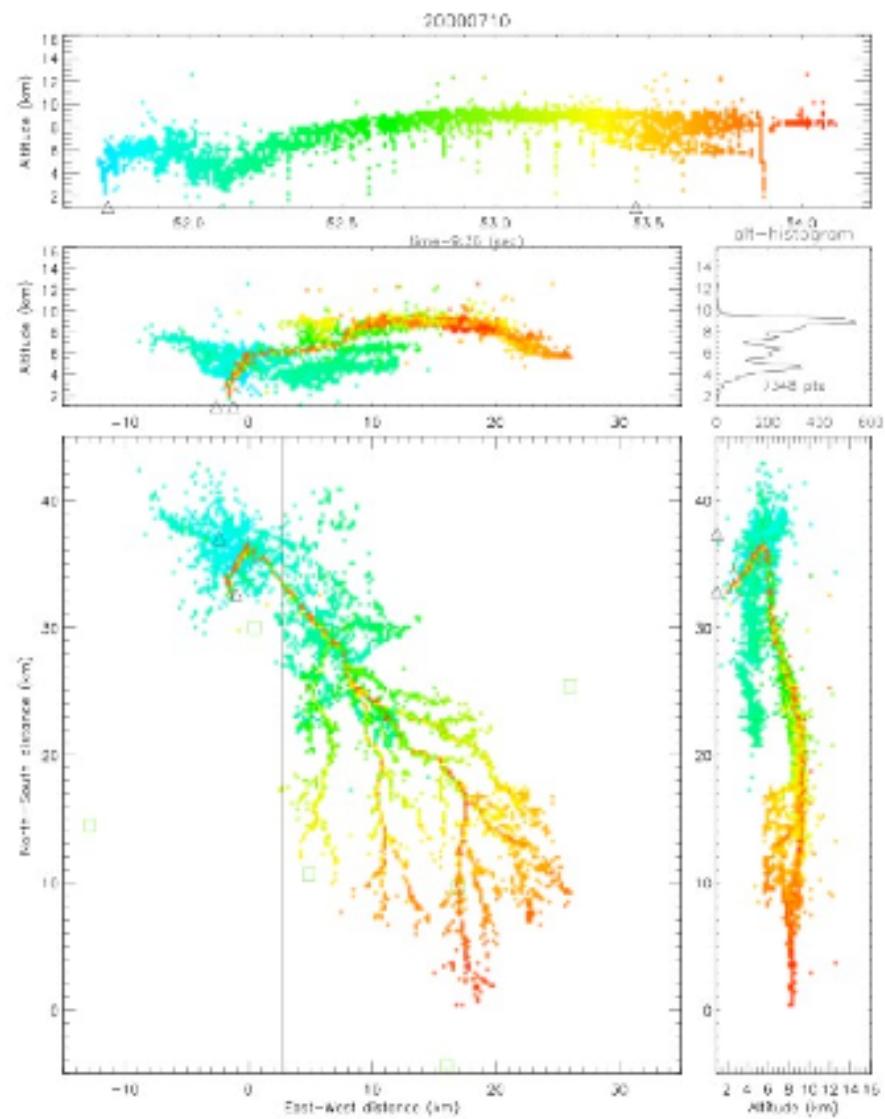
Lateral distribution



Good agreement

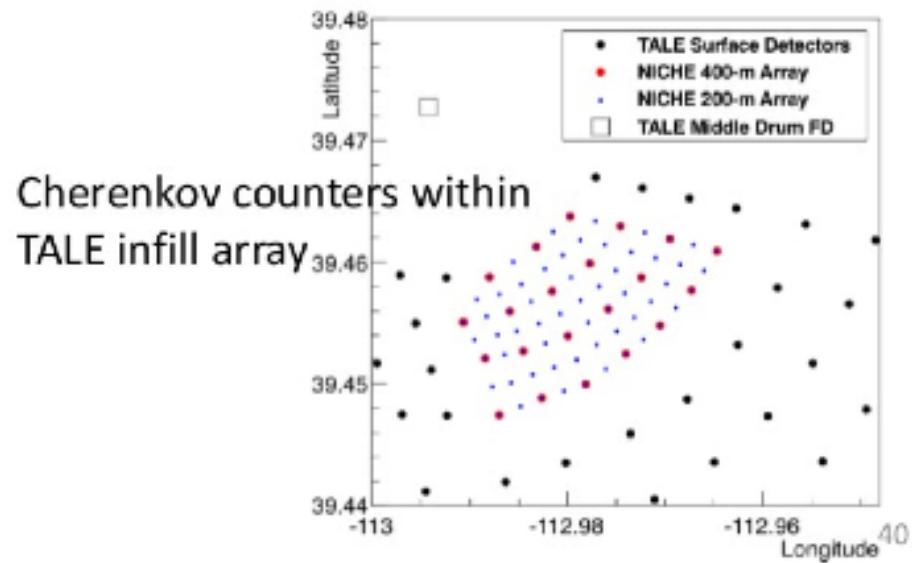
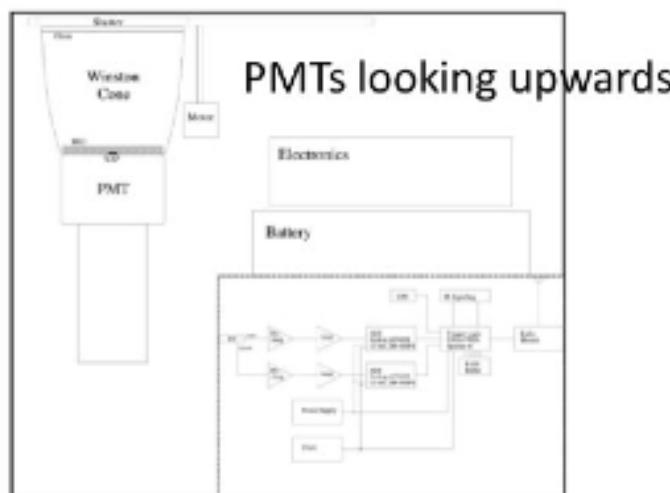
# TA/LMA: Lightning Mapping

- Cosmic rays *may* trigger lightning strikes.
- Lightning *does* emit air shower-like bursts of particles.
- Proposing to deploy lightning mapping array (LMA) at TA to study these phenomena.



# NICHE project

- Non-Imaging CHerenkov Array (NICHE)
- TA/TALE extension to measure the the **energy** and **composition (Xmax)** of very-high energy cosmic rays
  - $E = 10^{15.5}$  to  $10^{17}$  eV
  - Proposed but not yet funded



# Conclusions ( Physics )

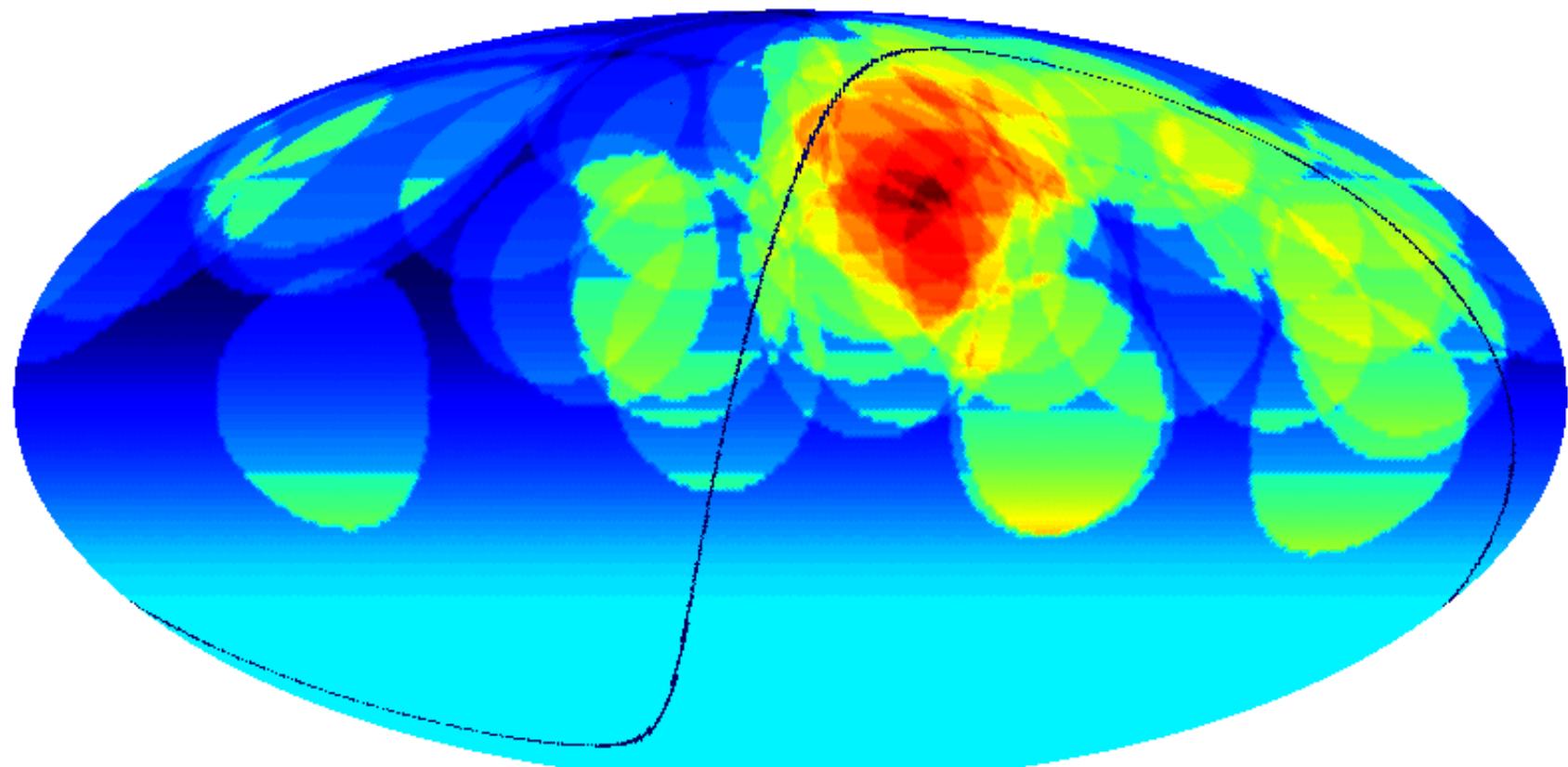
- GZK cutoff confirmed at  $> 5$  sigma level with AGASA-like SD array calibrated with FD.
- Composition looks light, but detailed comparisons with PAO results in process.
- Interesting  $\sim 3$  sigma correlation at highest energies with LSS within  $\sim 100$  Mpc. Hot spot off the Super-galactic plane may be emerging.

# Conclusions ( projects )

- Major expansion of SD to TAx4 proposed.
- Full power TARA is now taking data
- ELS providing end-to-end calibration and valuable resource for radio/fluorescence and JRM-EUSO calibration
- Low energy extensions – TALE currently in test data taking
- NICHE and TALMA in proposal stage

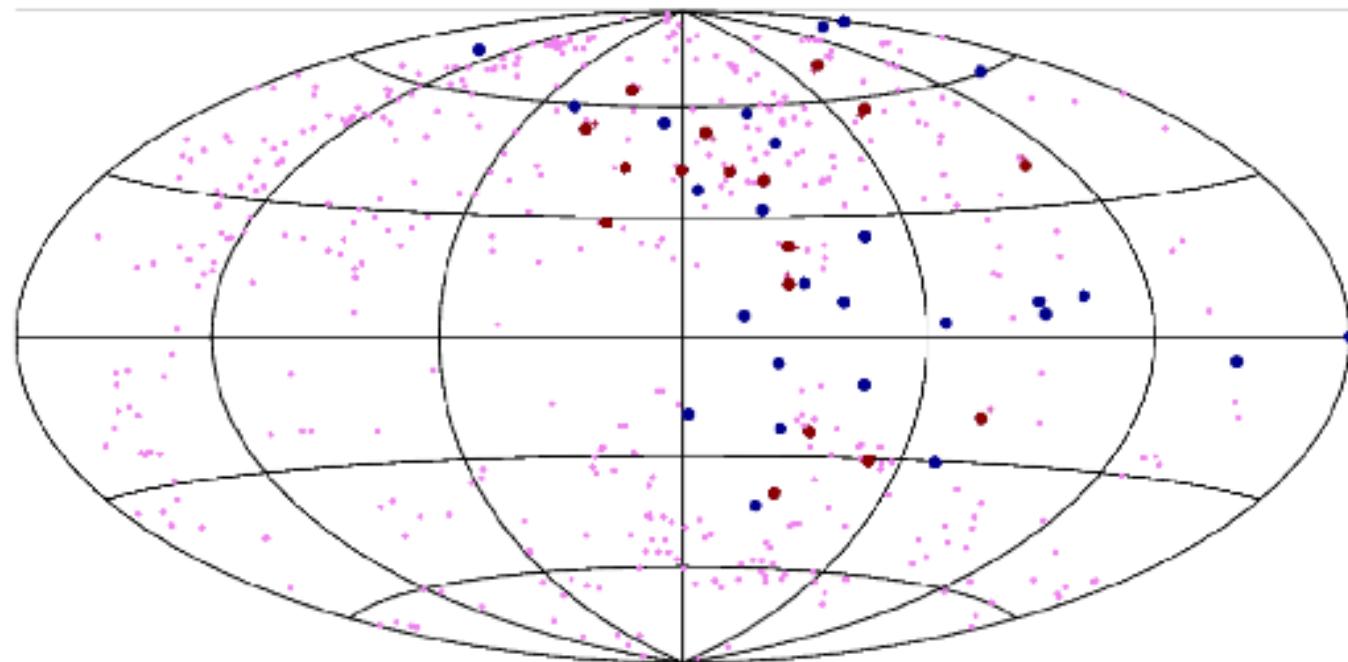
A photograph of a landscape at sunset. In the foreground, there is a field of low-lying shrubs and patches of snow. A tall, dark metal antenna tower stands prominently in the center. To its left, a small, dark, rectangular building with a flag on top sits on a hill. The sky is filled with dramatic, wispy clouds colored in shades of orange, yellow, and blue. In the distance, a range of mountains is visible under the setting sun.

Thank You

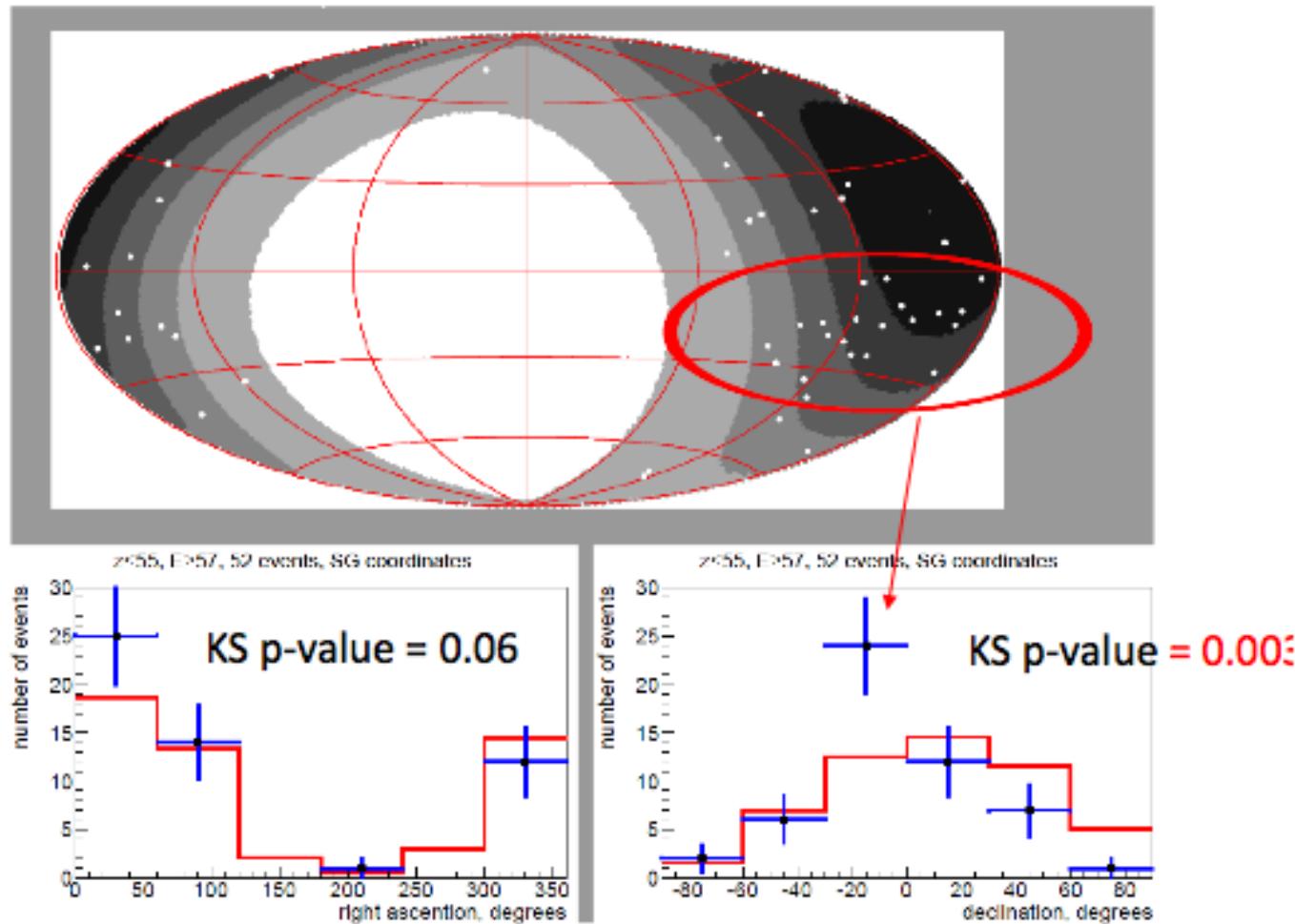


-2.46 +4.10

- 472 AGN from 2006 Veron catalog with  $z < 0.018$
- $E > 57 \text{ EeV}$ , zenith angle  $< 45^\circ$ ,  $N = 42$  (5 yr)
- Separation angle =  $3.1^\circ$



# Super galactic coordinates

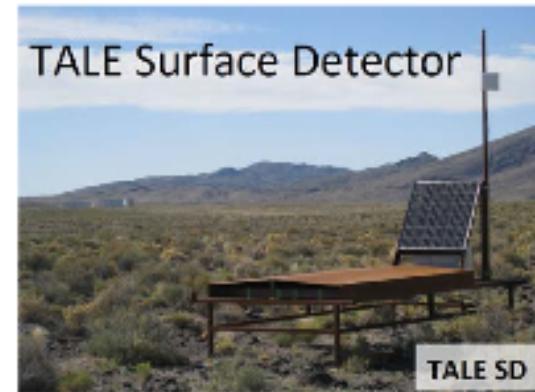


- Measured average fluorescence yield ( $\langle \text{measured FY} \rangle$ )
  - The case of TA fluorescence yield (TA-FY) model
    - Spectrum: FLASH model, Astropart Physics 29 (2008) 77-86
    - Absolute yield: Kakimoto et al., NIM-A 372 (1996) 527-533
    - $$\frac{\langle \text{measured FY} \rangle}{\text{TA FY}} = 1.18 \pm 0.01(\text{stat}) \pm 0.18(\text{syst})$$
  - The case of common model CM-FY2012
    - Spectrum: B. Keihauer et al., Proc. UHECR2012, arXiv:astro-ph/1210.1319
    - Absolute yield: AirFly meas. chosen here, arXiv:1210.6734 [astro-ph.IM]
    - $$\frac{\langle \text{measured FY} \rangle}{\text{CM-FY2012}} = 0.96 \pm 0.01(\text{stat}) \pm 0.15(\text{syst})$$

- 10 TALE FDs:
  - refurbished HiRes-II telescopes
  - installed and running.

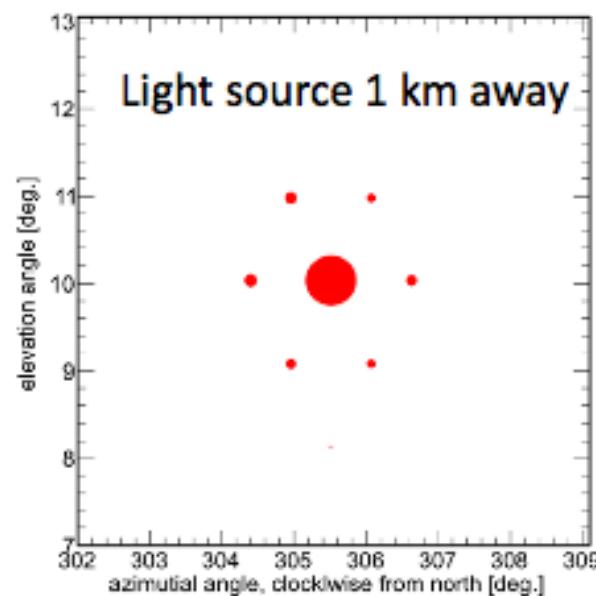


- TALE SDs
  - 35 TALE SDs were deployed among 101 SDs.
  - 16 in operation



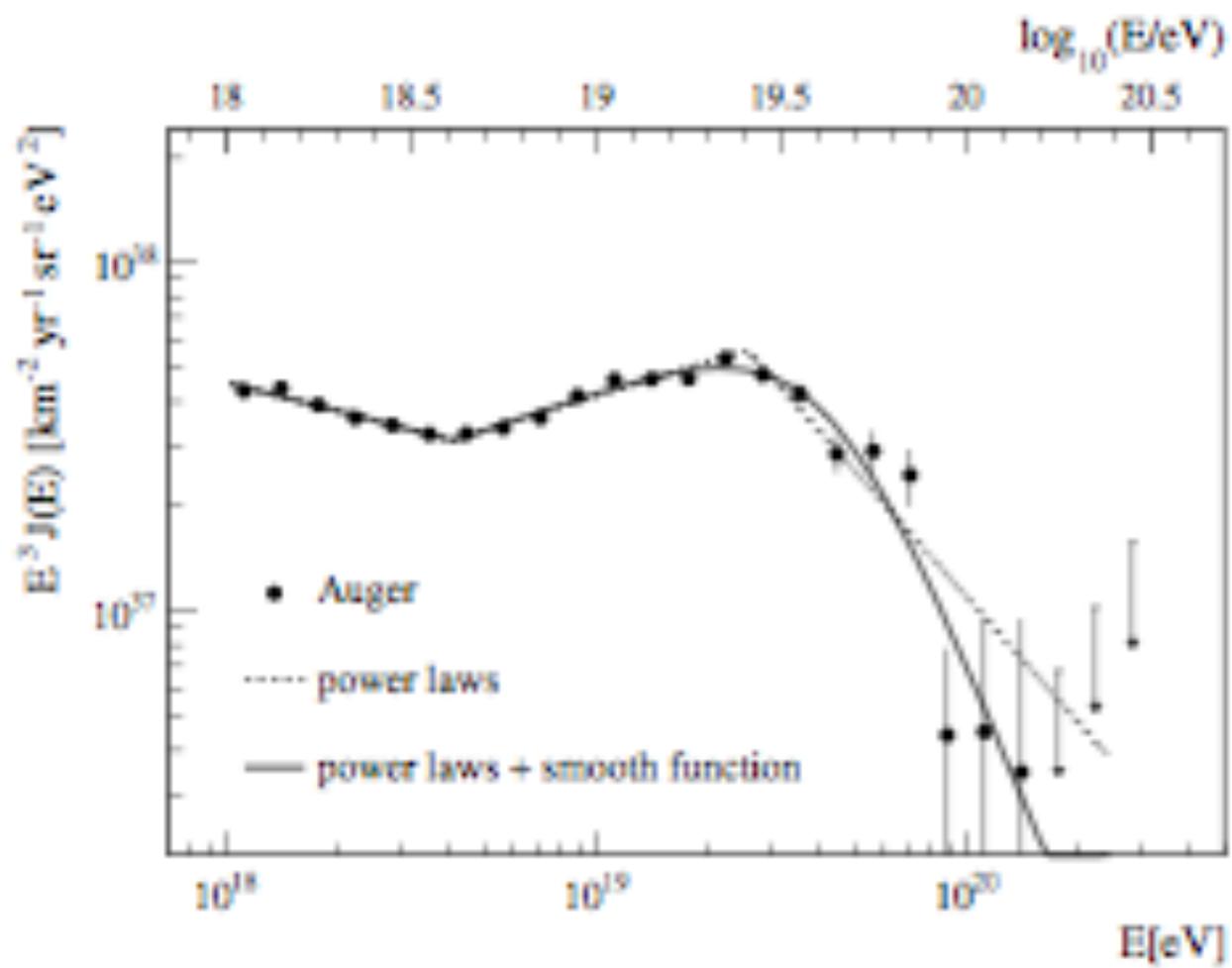
# Light Source Test

- A joint calibration campaign for the fluorescence telescopes
  - Optical end-to-end calibration with a portable calibrated light source carried by an octocopter provided by Auger
  - Known position: GPS



Data with TA FD

# PAO Spectrum



# PAO Composition

